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Maize for bread under organic agriculture

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Abstract

Maize (*Zea mays* L.) bread is increasingly appreciated by consumers from the northwest of the Iberian Peninsula. However, the ancient maize varieties specifically selected for those uses have been replaced by hybrids with higher yield and lower flour quality. Besides, maize available comes from intensive agriculture, involving herbicides, insecticides and other potentially dangerous products. Organic production of traditional maize varieties for human consumption could be valuable for raising the returns of small local farmers in the northwest of Spain and the north of Portugal, and for matching the demands of consumers. Autochthonous varieties have been evaluated under organic farming and the quality of those with higher yield for bakery. Four autochthonous varieties were identified with the best performance under organic conditions and adequate quality for making bread and other traditional maize foods. Those varieties are 'Tuy' (yellow kernel and medium growing cycle), 'Sarreaus' (yellow kernel and early cycle), 'Meiro' (black kernel and late cycle), and 'Rebordanes' (white kernel and medium-early cycle). Traditional white, yellow and black maize varieties have been identified, and a selection program for increasing yield and quality is being performed for each.

Additional key words: flour, germplasm, quality, *Zea mays*.

Resumen

Maíz para pan en agricultura ecológica

El pan de maíz (*Zea mays* L.) es cada vez más apreciado por los consumidores del noroeste de la Península Ibérica. Sin embargo, las antiguas variedades de maíz específicamente seleccionadas para esos usos han sido reemplazadas por híbridos con mayor rendimiento y menor calidad harinera. Además, el maíz disponible procede de agricultura intensiva, donde se usan herbicidas, insecticidas y otros productos potencialmente peligrosos para la salud. La producción ecológica de variedades tradicionales de maíz para consumo humano puede ser útil para aumentar los beneficios de los pequeños agricultores locales en el noroeste de España y norte de Portugal, así como para satisfacer las demandas de los consumidores. En este trabajo hemos evaluado variedades autóctonas en condiciones de agricultura ecológica y la calidad panificable de las variedades con mayores rendimientos. Hemos identificado cuatro variedades autóctonas con el mayor valor agronómico en condiciones de agricultura ecológica y calidad satisfactoria para hacer pan de maíz y otros alimentos tradicionales de maíz. Estas variedades son 'Tuy' (grano amarillo y ciclo medio), 'Sarreaus' (grano amarillo y temprana), 'Meiro' (grano negro y tardía), y 'Rebordanes' (grano blanco y ciclo medio). Estas variedades tradicionales de maíz blanco, amarillo y negro están siendo mejoradas para aumentar el rendimiento harinero.

Palabras clave adicionales: calidad, germoplasma, harina, *Zea mays*.

Introduction[1]

Maize (*Zea mays* L.) is an important crop in the northwest of the Iberian Peninsula, where it is cultivated for self consumption in small farms. With the introduction of hybrids under intensive cropping systems, the traditional uses of maize are being abandoned, as part of a general crisis of agriculture in that area. The rural decay causes social, environmental, and economical negative consequences.

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[1] Abbreviations used: CSIC (Consejo Superior de Investigaciones Científicas), LSD (least significant difference).

Maize was introduced in the northwest of Spain four centuries ago (Revilla *et al*., 2003). Since then maize has been used both for feed and for food. Along that period, very different varieties have been selected for adaptation to diverse environments and for consumer preferences. Most autochthonous varieties from that area are vigorous, flint, and with a short cycle and a low though stable yield, compared to modern hybrids.

Maize bread, a peculiarity of this region, is made traditionally with whole flint maize kernels. Local consumers believe flint kernels produce better flour and have better cooking characteristics and flavor than dent kernels (Landa *et al*., 2006). There is a large variability among autochthonous maize varieties concerning growing cycle, plant architecture, and kernel characteristics.

The introduction of maize hybrids in the northwest of Spain started in the 1920s, but progressed slowly due to the lack of adaptation to the environment and to the resistance of farmers who cultivated maize mainly for self-consumption (Revilla *et al*., 2003). However, the crisis of traditional farming systems has caused the disappearance of autochthonous varieties from the rural landscape. Modern hybrids overcome ancient varieties for yield, but lack adaptation and require intensive inputs of nutrients, herbicides, insecticides, and irrigation. Besides, ancient varieties are more appropriate for manufacturing maize bread and other traditional specialties. Nowadays bakers cannot obtain enough amount of maize flour traditionally selected for maize bread and pies.

Autochthonous varieties are available from germplasm banks. The Misión Biológica de Galicia (Consejo Superior de Investigaciones Científicas, CSIC) maintains a collection of local varieties, including an extensive sample from the Northwest of Spain which includes some varieties formerly used for making bread. That collection has been characterized and evaluated for a number of traits, not including kernel quality for bakery. Bakery quality has not been defined for maize bread, although some criteria can be valid, such as large kernel size, uniformity, high density, and lack of physical damage, pests, and diseases (Watson, 1988; Serna-Saldivar *et al.,* 2001; Alonso-Ferro *et al.,* 2008).

Grain contamination with hazardous chemicals is an increasing concern for consumers, which has resulted in a rising demand of organic products. Traditional products for human consumption and organic agriculture would increase the added value of small farms that are in decline today.

In the Northwest of the Iberian Peninsula, maize bread is traditionally made with whole grain of maize, following similar procedures as for manufacturing the common wheat bread. Originally, maize bread replaced other cereals in areas where wheat was not easily available, with variations in preferences associated to the geographical preferences. Differences mainly concern kernel color, which could be white, yellow or black. These colors are also used in other parts of the World, although white kernel is preferred because lacks pigments that could result in undesirable flavors and smells (Serna-Saldivar *et al*., 2001).

The company Promotora Orxeira S.A. intends the reinstatement of traditional varieties for baking, under organic agriculture (Landa *et al*., 2006). The objective of this work was the evaluation of autochthonous varieties for bakery quality under organic agriculture conditions.

Material and Methods

A sample of maize populations from the Northwest of the Iberian Peninsula, was evaluated under organic agriculture in two fields located in Ermille (Lobeira 41° 60' N, 8° 02' W) and Parada (Muiños 41° 56' N, 7° 57' W), both in the province of Ourense, northwestern Spain, at 600 m above sea level. Trials followed an experimental design of randomized complete blocks with three replications. Experimental plots of 10 m^2 had a density of 60,000 plants ha^{-1}, with rows separated 0.8 m and plants within rows 0.21 m. Organic manure was added before sowing, irrigation was made only in Ermille, when necessary, and weeds were controlled both mechanically and manually. Agricultural practices were similar in both locations, and followed the recommendations of organic agriculture, i.e. nutrients were supplied by adding manure, weeds were removed mechanically, and no chemical treatment was used.

Agronomic traits recorded were grain yield (Mg ha^{-1} at 140 g H_2O kg^{-1}), grain moisture (g kg^{-1}), milling test (%), and kernel density (g mL^{-1}), although kernel density was not recorded in 2005. Milling test was an estimation of the resistance of kernels to produce flour in a coffee mill; it was defined as the percentage of flour produced in a limited time. The milling test consisted on grinding 50 g of whole kernel in a coffee mill for 1 min, sieving for 1 min in a sieve with 1 mm orifices, and weighting the remaining fraction. Milling test was calculated as 100 × (kernel weight – remaining fraction) / kernel weight. The method for estimating kernel density was to pour 50 g of whole grain in a test-tube containing 50 mL of 95% ethanol, and to record the final volume of the mixture. Kernel density was estimated as kernel weight / (final volume – initial volume).

After harvest, grain was stored until next spring. Each year, the varieties with higher yield for each kernel color were ground and the flour was used for making a piece of bread for each experimental plot. Bread was made according to the following procedure:

— Ingredients: 600 g of whole grain maize flour, 300 g of whole grain wheat flour, 3 g of lyophilized yeast (*Saccharomyces cerevisae* Meyer ex Hansen), 560 g of water, 19 g of sodium chloride.

— Method: Maize and wheat flours were mixed with the yeast. The salt was solved in warm water. The water was added to the flour mixture and mechanically kneaded for 10 min. Fermentation was allowed in the dark, for one hour, covered with a humid cloth. Finally, cooking was made in an oven for one hour at 200°C.

The bread pieces were tasted after cooling down to room temperature. Bread was tasted by a random panel of eight members with diverse ages, sexes, and geographical origins. The traits recorded were cooking degree (visual scale from 1 = uncooked to 9 = overcooked), appearance (visual scale from 1 = disgusting to 9 = attractive), texture (subjective scale from 1 = smooth to 9 = granulated), hardness (subjective scale from 1 = soft to 9 = hard), flavor (subjective scale from 1 = disgusting to 9 = attractive), smell (subjective scale from 1=disgusting to 9 = attractive), and uniformity (visual scale from 1 = irregular to 9 = homogeneous). Based on the analyses of 2003 and 2004, in 2005 the number of parameters for estimating bread quality was reduced to appearance, flavor, and uniformity. Analyses of variance were performed for quality traits following the same design than for agronomic traits. All analyses were made with the procedure GLM of the statistical package SAS (2002).

Seventeen varieties were evaluated in 2003. The analyses of variance showed significant differences among varieties and the mean comparisons were used to select the varieties with largest yield and lower grain moisture within each color. The other traits were also considered for the election of varieties, particularly density and milling test, and the varieties chosen were evaluated for baking quality by the tasting panel. From these analyses, the varietes chosen were the yellow-kernel varieties, EPS21(FR)C1, Sarreaus and Tuy(S)C1, the black-kernel variety Meiro, and the white-kernel variety Rebordanes, which were evaluated in 2004, along with six new varieties. The previously described analyses were also applied to choose the best varieties from 2004 trials, namely Sarreaus, Tuy(S)C1, Meiro and PRT01493, which were evaluated again in 2005 along with nine more varieties (Table 1).

Results

Agronomic data

The genotype × location interaction was not significant in any particular year, while the differences among populations were significant for all traits. In 2003, the population with best agronomic performance was EPS21(FR)C1, followed by Tuy(S)C1, Meiro, and Sarreaus, all of them with yellow kernels, except Meiro, that had black kernels. EPS21(FR)C1 has semi-flint and semi-dent kernels and Meiro had a large kernel moisture (Table 2). Tuy(S)C1 and Sarreaus showed favorable values for yield components, while Meiro and Rebordanes had intermediate values (data not shown). Milling test was highest for Blanco though differences were not significant for half of the varieties, including the highest yielders. Milling test was lowest for PRT00100049 that had the highest kernel density, along with five more varieties. Among the varieties with highest yield, only EPS21(FR)C1 had also high density (Table 2).

The varieties with highest yield in 2004 were Tuy(S)C1, Meiro, EPS21(FR)C1 and PRT01493 (Table 3). EPS21(FR)C1 and PRT01493 also had low grain moisture, along with Sarreaus, Verea and PRT02141. Tuy(S)C1 was the yellow-kernel variety with highest yield, but Sarreaus had lowest grain moisture. The white variety PRT01493 had the best performance, though not differing significantly from Rebordanes. And the black-kernel variety Meiro had a satisfactory performance.

The black variety Meiro had the highest yield, although also the highest grain moisture, followed by the yellow-kernel variety Tuy (S)C1 (Table 4). The white-kernel variety with highest yield was Rebordanes(S)C1. Among the early varieties, Gaxate and Rebordanes(S)C1 had large yield. Differences among varieties for milling test were not significant, and those varieties with highest grain yield had intermediate milling test values.

Table 1. Maize varieties evauated under organic conditions during one, two or three years at two locations of the northwest of Spain

Population[a]	Cycle and kernel color	Years of evaluation
Arzúa	Early yellow	2003
Blanco	Late white	2003
Celanova	Early yellow	2005
Conchas	Late yellow	2004
EPS14(FR)C3	Medium yellow improved synthetic	2005
EPS21(FR)C1	Early yellow improved synthetic	2003-04
EPS33	Medium-early synthetic	2005
Gallego	Medium-early miscellaneous color	2003
Gaxate	Early yellow	2005
Golada	Medium-early yellow	2003
Lalín	Early yellow	2005
Meiro	Late black	2003-04-05
PRT00101493	Early white	2004-05
PRT00101537	Late white	2004
PRT00102141	Medium-early white	2004
PRT00102144	Late white	2004
PRT00100049	Medium-early yellow	2003
PRT00100392	Medium-early white	2003
PRT00101526	Early yellow	2003
Puenteareas	Medium-early yellow	2005
Puertomarín	Medium-early yellow	2003
Ramiranes	Medium-early white and red	2003
Rebordanes	Medium early white	2003-04
Rebordanes(F)C1	Medium early white improved for cold tolerance	2003
Rebordanes(S)C1	Medium early white improved for yield	2005
Regadas	Medium early white	2003
Ribadumia(S)C1	Medium early white improved for yield	2005
Santiago(F)C1	Medium early yellow improved for cold tolerance	2003
Sarreaus	Early yellow	2003-04-05
Tuy(S)C1	Medium yellow improvement for yield	2003-04-05
Valongo	Medium early yellow	2005
Verea	Medium early white	2004

[a] These populations belong to the collection of the Misión Biológica de Galicia (CSIC), except those with codes beginning with PRT that were provided by the Portuguese Bank of Germplasm.

Quality

In 2003, the varieties differed significantly only for cooking degree and appearance (Table 5). In 2004, the differences among varieties were significant for appearance and uniformity (Table 5). In the analyses of variance combined over 2003 and 2004, using the common varieties, the differences among varieties were significant for appearance, flavor, and uniformity. Therefore, only these traits were analyzed in 2005 (Table 5).

In 2003, Tuy(S)C1 had the highest quality and Rebordanes the worst. In 2004, Rebordanes had the largest values of quality, although the other varieties were not significantly different except Meiro. In the combined analysis of variance over 2003 and 2004, Meiro had the worst appearance. In both years, as well as in the combined analysis of variance, Tuy(S)C1 had the best flavor, and Meiro the worst flavor and the lowest uniformity.

All varieties tested had an acceptable quality, and those with yellow kernels had slightly superior qualifications. Tuy(S)C1 was one of the varieties with best flavor, smell, appearance, and uniformity, while Sarreaus stood out for cooking degree. The black-kernel Meiro got the worst qualifications in the combined analyses over 2003 and 2004 (data not shown). In 2005, differences among varieties were not significant, but the qualifications for Tuy(S)C1 were high for appearance, and one of the new varieties of the year, Gaxate, overcomes Tuy(S)C1 on flavor.

Table 2. Means of maize varieties evaluated under organic agriculture at two locations in 2003

Variety	Grain yield (Mg ha^{-1})	Grain moisture (g kg^{-1})	Milling test (%)	Kernel density (g mL^{-1})
Tuy(S)C1	8.1a	268b	56.7ab	1.22fg
Meiro	7.6a	292a	55.1abcd	1.24cdefg
EPS21(FR)C1	8.5a	227fg	56.7ab	1.26abc
Sarreaus	6.4b	240def	54.4abcd	1.23defg
Rebordanes	6.3bc	256bcd	49.4de	1.25bcdef
Rebordanes(F)C1	6.1bcd	240def	50.5cde	1.24cdefg
Regadas	5.4bcde	225fg	52.5bcde	1.21g
PRT00100392	5.3bcde	252bcd	54.3abcd	1.23efg
Gallego	5.2cde	249cd	54.8abcd	1.21g
Ramiranes	5.1def	224fg	54.3abcd	1.21g
Blanco	5.1def	308a	58.7a	1.26abcd
PRT00100049	5.0ef	260bc	47.7e	1.27a
Santiago(F)C1	4.9ef	220g	55.6abc	1.25abcde
Golada	4.7ef	266b	51.4bcde	1.24cdefg
PRT00101526	4.4ef	232efg	52.5bcde	1.27ab
Arzúa	4.3ef	241def	50.8cde	1.25abcde
Puertomarín	4.1f	248cde	51.6bcde	1.21g

Means followed by the same letter, within the same column, are not significantly different (LSD at P = 0.5).

Discussion

The germplasm collection evaluated has a broad genetic base; consequently differences among genotypes were large for most traits, while the genotype × environment interaction was not important. Therefore, the election of varieties is quite trustworthy. Other authors dealing with more or less wide collections of maize varieties for human consumption have found diverse results concerning the importance of the genetic differences and the genotype × environment interaction (LeFord and Russell, 1985; Duarte *et al*., 2005; Malvar *et al*., 2008).

Table 3. Means of maize varieties evaluated under organic agriculture at two locations in 2004

Variety	Grain yield (Mg ha^{-1})	Grain moisture (g kg^{-1})	Milling test (%)	Kernel density (g mL^{-1})
Tuy(S)C1	7.1a	246de	66.1abcd	1.22
Meiro	6.9a	251cd	62.8cd	1.28
EPS21(FR)C1	6.2ab	235ef	62.5d	1.27
PRT01493	5.7abc	240def	65.4abcd	1.27
PRT01537	5.6abcd	287a	62.5d	1.23
PRT02141	5.3bcde	240def	63.6bcd	1.24
PRT02144	4.9bcde	262bc	62.3d	1.27
Sarreaus	4.8bcde	226f	69.3abc	1.22
Rebordanes	4.2cde	245de	62.7cd	1.26
Conchas	4.2de	265b	71.6a	1.22
Verea	4.1e	227f	69.5ab	1.22

Means followed by the same letter, within the same column, are not significantly different (LSD at P = 0.5).

Table 4. Means of maize varieties evaluated under organic agriculture at two locations in 2005

Variety	Grain yield (Mg ha^{-1})	Grain moisture (g kg^{-1})	Milling test (%)
Meiro	7.0a	240b	66a
Tuy(S)C1	5.8ab	237bc	62ab
Gaxate	5.6b	214def	65a
Valongo	5.6b	221de	62ab
Rebordanes(S)C1	5.4bc	210ef	65a
Ribadumia(S)C1	5.4bc	255a	65a
Rebordanes	5.3bc	222de	62ab
EPS13(FR)C13	5.2bcd	223d	64a
EPS33	5.1bcd	225cd	62ab
Sarreaus	4.8b-e	212def	62a
EPS14(FR)C3	4.7b-f	223d	66a
Puenteareas	4.3c-f	220de	62ab
PRT01493	4.1def	224de	57b
Celanova	3.6ef	213def	61ab
Lalín	3.5f	205f	62ab

Means followed by the same letter, within the same column, are not significantly different (LSD at P = 0.5).

Several yellow varieties showed adequate yield under organic conditions, particularly Tuy, while the only white variety with comparable agronomic performance was Rebordanes. There is, actually, more variability available among yellow than among white germplasm, probably because white maize has some problems with seed health or because of farmer preferences (Troyer, 1999). Besides, the genetic base of white germplasm of maize is narrower than that of yellow corn because white corn is maintained for specific uses and cannot be crossed with yellow corn if the white color is important. Nevertheless, from these results the conclusion is that yellow, white, or black maize varieties with adequate yield, are available for organic farming.

Quality requirements are stricter for human consumption than for feed and involve purity of the white color, large uniform size of kernels, high specific density, hard endosperm, and white cob (Watson, 1988). Baking quality is lower for maize than for wheat (He and Hoseney, 1991). Generally, yellow maize is preferred for feed because contains carotenoids (Troyer, 1999); on the other hand, white maize is preferred for

Table 5. Mean comparisons for taste qualifications of the varieties with higher agronomic performance in 2003, 2004 and 2005. All traits have been rated with a subjective scale from 1 = low or poor, to 9 = high or good

Variety	Cooking degree	Appearance	Texture	Hardness	Flavor	Smell	Uniformity
Year 2003							
EPS21(FR)C1	5.6ab	7.0b	5.7a	6.8a	6.8ab	6.1a	6.6a
Rebordanes	5.4b	5.9d	5.6a	6.3a	6.8ab	6.1a	6.5a
Sarreaus	5.8a	6.6c	5.6a	6.3a	6.3ab	6.0a	6.5a
Tuy(S)C1	5.8a	7.8a	5.9a	7.3a	7.2a	6.5a	6.5a
Year 2004							
Meiro	5.5a	6.2b	5.8a	6.0a	6.8a	6.8a	6.3c
PRT00101493	5.6a	6.9ab	5.8a	6.3a	7.4a	7.1a	6.6ab
Rebordanes	5.6a	7.5a	5.9a	6.2a	7.4a	7.2a	6.4bc
Sarreaus	5.8a	7.1ab	6.1a	6.3a	7.2a	7.3a	6.7a
Tuy(S)C1	5.6a	7.2a	6.2a	6.1a	7.5a	7.2a	6.6a
Year 2005							
Gaxate		7.24a			7.70a		6.88a
Rebordanes(S)C1		7.12a			7.42a		7.06a
Tuy(S)C1		7.27a			7.42a		7.15a
Valongo		6.94a			7.18a		7.12a

Means followed by the same letter, within the same column and year, are not significantly different (LSD at P = 0.05).

human consumption because degradation of carotenoids during baking or frying causes too strong aroma and flavor (Poneleit, 2001). These results show that the relationship among kernel color and quality is not straightforward and that the hedonic qualification of the diverse varieties was similar. However, the panel qualified slightly better the yellow variety Tuy. The reason for such discrepancy with common preferences could be the local preferences of people from the northwest of the Iberian Peninsula that have been using yellow or white maize for the traditional food during four centuries.

There was not a clear pattern of relationship among agronomic performance, kernel quality, and hedonic rate across varieties. In fact, the relationships among agronomic and quality traits are inconsistent for the diverse materials evaluated here, which suggest that both kinds of traits can be improved independently. However, these are complex traits, and their improvement is not straightforward (Alonso Ferro *et al.*, 2008; Malvar *et al.*, 2008).

In conclusion, some local varieties have been identified with white, yellow, and black kernels, appropriate for bakery. These varieties have been evaluated under organic agriculture, showing an appropriate agronomic performance and acceptable quality. No relationship between yield and quality has been found, and the varieties improved under conventional agriculture are adequate for organic agriculture as well.

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